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16. ABSTRACT

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The field data reflects an approximate 10% reduction in arch deflection through the use of cable ties. Deflections observed in the field were 18% less than calculated deflections. Factors that are not usually considered in calculating arch stiffness, but could have contributed to the apparent greater stiffness are listed in the report.

The test loads were one-quarter of theoretical design loads. The report concludes that the results are applicable to the loads and tested structure only and that one should not infer that an extrapolation can be made for other loads or other structures. A reasonable assumption, however, is that other loads would cause less deflection than would be indicated by theoretical calculations on a similar structure.

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STATE OF CALIFORNIA
HIGHWAY TRANSPORTATION AGENCY
DEPARTMENT OF PUBLIC WORKS
DIVISION OF HIGHWAYS

BRIDGE DEPARTMENT

July 1964

COLD SPRING CANYON ARCH DEFLECTION STUDY

Prepared in Cooperation with
The U.S. Department of Commerce,
Bureau of Public Roads

COLD SPRING CANYON ARCH

DEFLECTION STUDY

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Cold Spring Canyon Arch
Deflection Study

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COLD SPRING CANYON ARCH DEFLECTION STUDY

INTRODUCTION

The alignment of State Highway 80 from Santa Barbara to Lake Cachuma was recently improved by the construction of a 1,218 foot structure across Cold Spring Canyon. The two lane deck of this structure is supported on spandrel columns from twin 2 hinged steel arch ribs, that span 700 feet over the deeper portion of the canyon, and steel column supported approach spans. Except for the tower columns above the arch skew back, all columns are hinged at both the top and bottom in the longitudinal direction. All thermal movements in the superstructure are directed through an expansion bearing at the southerly abutment. The northerly abutment resists all longitudinal forces that occur in the superstructure.

Two 1 5/8" diameter longitudinal cables, located at the crown of each rib, tie the arch to the superstructure. These cable ties reduce arch deflection under unsymmetrical loading by providing some restraint against translation of the arch. Theoretical calculations based on the deflection theory indicate a 25% reduction in arch deflection by this method of stiffening the arch through the superstructure.

The use of cable ties to increase the stiffness of a steel arch is a unique application in this design and no information is available on the actual quantitative effect of such ties. A field study of vertical deflections was conducted for the purpose of determining the effectiveness of cable ties in increasing the stiffness of a steel arch. A study of horizontal deflections was not undertaken because of the complex instrumentation that would have been required at this difficult site.

PROCEDURE

A control load was positioned above a panel point and vertical deflection measurements were taken at all panel points. This procedure was repeated until all panel points had been subjected to the load. The same procedure was repeated three times for each condition of active and inactive cable ties. The data from the two conditions were compared. In addition to the deflection readings, the loads on the cables were also recorded during the cable active phase of testing.

Control Load

The control load consisted of two 38.5 ton Model B Le Tourneau Westinghouse Tourneau Rockers. (Figure 2) These vehicles were symmetrically placed on each side of the deck centerline in the dump position, with their front and rear axles equal distance from the panel point. When in the dump position, the center to center spacing of the front and rear axles was 12', with a respective loading of 34 and 43 kips on the front and rear axles. This loading arrangement caused an approximate 150 kips load on the straddled panel point, with approximately 2 kips distributed to each adjacent panel point through the continuous deck system.

Deflection Measurements

The position of a taut piano wire in reference to a scale attached to the curb of the structure represented deflection differentials.

The piano wire was attached to supports located above the skew back towers. It was made taut by anchoring one end and attaching heavy weights to the pulley supported other end.

The 12" steel scales were graduated in 1/100" and were secured by magnets and steel bars placed on the railing curb above the panel points.

The first series of measurements was made when the wind was sufficiently strong to cause severe vibrations in the piano wire and it was impossible to obtain readings of suitable accuracy. The piano wire method was therefore abandoned and elevation readings were taken with transits, located above the skew back towers, and level rods. Elevations recorded by this method were subsequently declared invalid due to numerous inconsistencies. The runs were duplicated on a more calm day using the piano wire method.

Very good accuracy was obtained in reading duplications using the piano wire method. 74% of the 200 sets of three deflection readings, that represented the three runs, had less than 0.05 inch differential between the high and low readings. Only 4% of the sets had a differential of over 0.10 inches. When there was as much as a 0.15 inch differential between the high and low readings, the third reading was usually very close to one of the outside readings. When this occurred, the average of the two close readings was recorded rather than the average of the three. All readings were adjusted to compensate for deflections caused by temperature changes.

Loads on the cable ties were measured by strain gauge load cells placed between the cable socket and nuts of the supporting "U" bolt.

RESULTS

The average deflection values of three runs with the cable ties in both an active and inactive condition and the percent difference in the two conditions are shown in Table I. Field measurements, for both active and inactive cable conditions, are compared with theoretical calculated deflections in Tables II and III.

The field data reflects an approximate 10% reduction in arch deflection by cable ties.

Field measurements were consistently lower than calculated deflections by approximately 18% for both active and inactive cable conditions. This implies greater arch stiffness than the typical cross-section properties of the arch indicate. Some of the arch properties that are not considered in theoretical calculations, but could contribute to this apparent greater stiffness are:

1. Vertical rigidity of the continuous deck system.

2. Lateral bracing system of the arch.

3. Friction in the column and arch pin connections.

4. Arch rib field splice connections. (There are 16 splice connections in each arch rib.)

No one of these factors when acting alone would affect the arch rib deflection appreciably, but when acting as a group, they could conceivably increase the stiffness sufficiently to effect an 18% decrease in deflections, especially with the relatively light loads used during testing.

The test loads were only one quarter of theoretical design loads. It is not known what effect this great a difference in loads would have on the validity of anticipated design load deflections obtained by extrapolating from these field deflection data. It is conceivable that the effect some of the arch properties have on the apparent stiffness of the arch would be lessened with a heavier load.

Changes in the length of the cable ties, calculated from recorded cable loads, were less than the arch displacements calculated for the test loads. The same arch properties that affected the vertical deflections probably were also responsible for this length-displacement variance. Other contributing factors would be 1) take-up in cable sag, and 2) deflection of stringer anchor connections.

Changes in cable loading due to live load application is shown in Table IV. The effect ambient temperature has on cable loading during live load application is reflected by the variation in the readings of the three runs for loading at a given panel point. Generally, as the temperature increased, the live load distribution decreased on the northwest cable and increased on the southwest cable. This temperature effected change in cable load was not, however, sufficiently large to cause a discernible pattern in the deflection behavior of the panel points during the three runs. Apparently the temperature differential would have to be much greater than the approximate 10 degrees experienced from the start of run 3 to the conclusion of run 5 to appreciably affect the participation of the cable ties.

A plot of cable load vs. ambient temperature, from readings that were taken over a 23 hour period, is shown in Figure 3. This plot reflects a cable load change of approximately 0.4 and 0.6 kips per degree change for the southwest and northwest cables, respectively.

CONCLUSIONS

The following conclusions are based on results obtained from specific loads used during this test and apply to the tested structure only. One should not infer that an extrapolation can be made for other loads or other structures. A reasonable conclusion, however, is that other loads would cause less deflection than would be indicated by theoretical calculations on a similar structure.

1. Longitudinal cable ties effect an approximate 10% decrease in arch deflections.

2. Measured vertical deflections were approximately 18% less than the theoretical calculated deflections for both active and inactive cable tie conditions.

3. Properties that affect arch stiffness, but are not included in theoretical calculations are: 1) vertical rigidity of the continuous deck system, 2) lateral bracing system of the arch, 3) friction in the column and arch pin connections, and 4) arch rib field splice connections.

4. Changes in ambient temperature affect cable live load distribution. However, the temperature change during the cable active phase of this test was not sufficient to influence arch deflections discernibly

ACKNOWLEDGEMENTS

George A. Hood, Jr., Senior Bridge Engineer, proposed this project and assisted in the planning and in the review of results. Theoretical calculations were made with the assistance of an IBM computer using a program written by George Fung. Fred Yoshino, Resident Engineer during construction of the arch, assisted in setting up the field study and in collecting field data. Bill Chow, Materials and Research Department, designed and built the cable tie load cells and assisted in taking field readings. Jack Holm, Wayne Harris and Harry Congdon of Bridge Construction loosened and tightened the cable ties as required and assisted in the collection of field data.

COLD SPRING CANYON ARCH
DEFLECTION STUDY

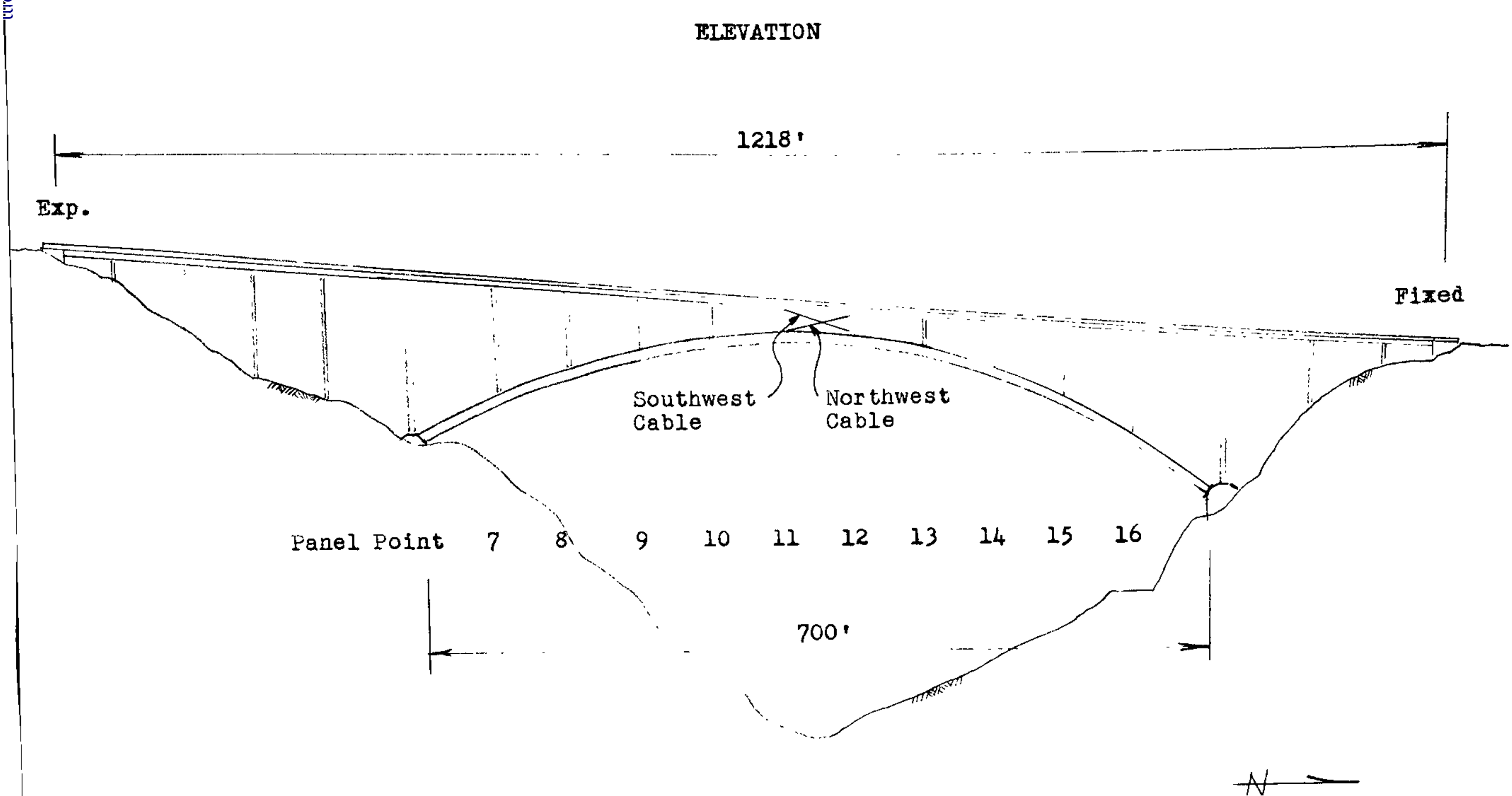
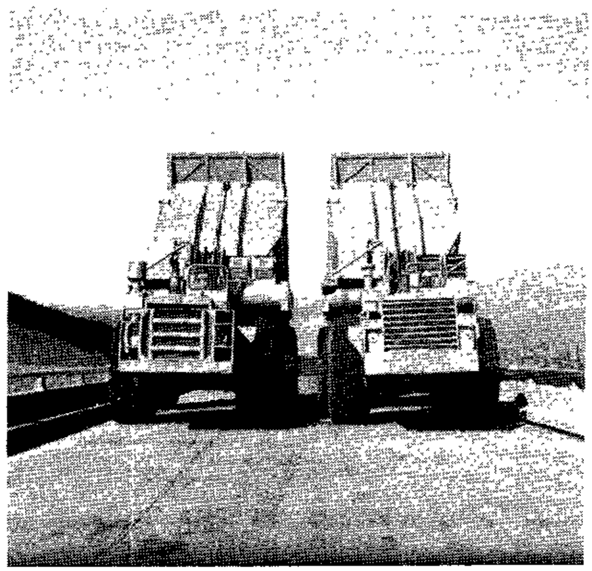
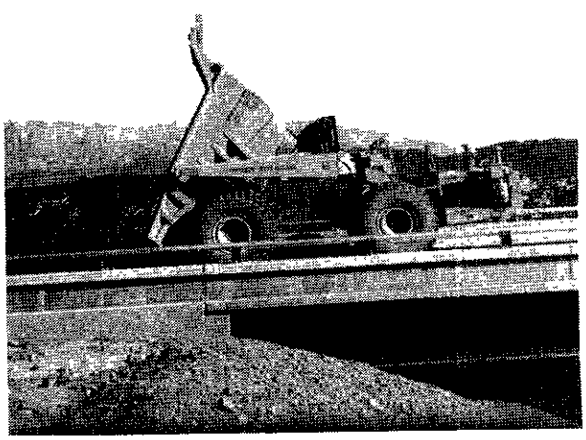


Figure 1

COLD SPRING CANYON ARCH
DEFLECTION STUDY

Test Load Vehicles





Le Tourneau Westinghouse model "B" Tourneau Rocker

Figure 2

COLD SPRING CANYON ARCH
DEFLECTION STUDY

FIELD MEASUREMENTS

VERTICAL DEFLECTIONS
(inches)

Load At	Cable Activity	7	8	9	10	11	12	13	14	15	16
		Average Deflection at Panel Points									
7	Inactive	-1.26	-1.55	-1.27	-0.68	+0.02	+0.65	+1.06	+1.19	+1.06	+0.63
	Active	-1.17	-1.50	-1.15	-0.58	0.00	+0.64	+0.96	+1.05	+0.89	+0.55
	% Change	7.1	3.2	9.5	14.7	-	1.5	9.4	11.8	16.0	12.7
8	Inactive	-1.53	-2.38	-2.17	-1.33	-0.19	+0.82	+1.67	+1.95	+1.75	+1.05
	Active	-1.41	-2.20	-1.95	-1.16	-0.16	+0.91	+1.53	+1.76	+1.56	+0.99
	% Change	7.9	7.6	10.1	12.8	-	11.0	8.4	9.8	11.8	5.7
9	Inactive	-1.20	-2.11	-2.39	-1.79	-0.61	+0.69	+1.68	+2.13	+1.98	+1.22
	Active	-1.10	-1.93	-2.21	-1.69	-0.59	+0.67	+1.53	+1.89	+1.78	+1.13
	% Change	8.3	8.5	7.5	5.6	3.3	2.9	8.9	11.3	10.1	7.4
10	Inactive	-0.60	-1.22	-1.73	-1.82	-1.10	+0.07	+1.11	+1.71	+1.73	+1.11
	Active	-0.48	-1.08	-1.56	-1.75	-1.08	+0.05	+1.00	+1.58	+1.58	+1.05
	% Change	20.0	11.5	10.0	3.8	1.8	-	9.9	7.6	8.7	5.4
11	Inactive	+0.10	-0.08	-0.52	-1.05	-1.28	-0.74	-0.08	+0.72	+0.97	+0.70
	Active	+0.12	-0.03	-0.53	-1.00	-1.27	-0.74	+0.04	+0.68	+0.92	+0.67
	% Change	-	-	0.0	4.8	0.0	0.0	-	5.5	5.2	4.3
12	Inactive	+0.71	+1.01	+0.75	+0.15	-0.68	-1.25	-1.08	-0.59	-0.13	+0.06
	Active	+0.64	+0.95	+0.75	+0.11	-0.71	-1.22	-1.03	-0.51	-0.08	+0.09
	% Change	9.9	5.9	0.0	-	4.4	2.4	4.6	13.5	-	-
13	Inactive	+1.10	+1.75	+1.76	+1.21	+0.18	-1.02	-1.82	-1.83	-1.34	-0.68
	Active	+1.01	+1.59	+1.64	+1.09	+0.15	-0.92	-1.71	-1.62	-1.10	-0.54
	% Change	8.2	9.1	6.8	9.9	-	9.8	5.5	11.5	18.0	20.6
14	Inactive	+1.21	+2.01	+2.19	+1.82	+0.82	-0.50	-1.78	-2.52	-2.28	-1.32
	Active	+1.10	+1.80	+1.98	+1.66	+0.77	-0.46	-1.62	-2.29	-2.05	-1.18
	% Change	9.1	10.4	9.6	8.8	6.1	8.0	9.0	9.1	10.0	10.6
15	Inactive	+1.03	+1.76	+2.00	+1.77	+1.03	-0.09	-1.29	-2.23	-2.58	-1.64
	Active	+0.92	+1.54	+1.80	+1.61	+0.97	-0.03	-1.13	-2.03	-2.34	-1.52
	% Change	10.7	12.5	10.0	9.0	5.8	-	12.4	9.0	9.3	7.3
16	Inactive	+0.59	+1.03	+1.19	+1.11	+0.72	+0.10	-0.62	-1.28	-1.64	-1.32
	Active	+0.54	+0.89	+1.09	+1.15	+0.64	+0.13	-0.53	-1.13	-1.48	-1.27
	% Change	8.5	13.6	8.4	3.6	11.1	-	14.5	11.7	9.8	3.8

Deflection measurements shown are average of 3 runs. - Down; + Up.
% change is not shown when deflections are less than 0.25 inch.

Average % change: 8.9

Table I

COLD SPRING CANYON ARCH
DEFLECTION STUDY

COMPARISON OF THEORETICAL AND MEASURED VERTICAL DEFLECTIONS
(inches)

CABLE TIES INACTIVE

Load At		Panel Point 7	8	9	10	11	12	13	14	15	16
7	Theo.	-1.39	-1.76	-1.42	-0.73	+0.07	+0.79	+1.24	+1.38	+1.21	+0.72
	Meas.	-1.26	-1.55	-1.27	-0.68	+0.02	+0.65	+1.06	+1.19	+1.06	+0.63
	% Diff.	9.4	11.9	11.5	6.9	-	17.7	14.5	13.8	12.4	12.5
8	Theo.	-1.84	-2.80	-2.56	-1.54	-0.16	+1.14	+2.04	+2.36	+2.12	+1.28
	Meas.	-1.53	-2.38	-2.17	-1.33	-0.19	+0.82	+1.67	+1.95	+1.75	+1.05
	% Diff.	16.8	15.0	15.2	13.6	-	28.1	18.1	17.4	17.5	18.0
9	Theo.	-1.56	-2.65	-2.93	-2.16	-0.68	+0.92	+2.15	+2.70	+2.52	+1.57
	Meas.	-1.20	-2.11	-2.39	-1.76	-0.61	+0.69	+1.68	+2.13	+1.98	+1.22
	% Diff.	23.0	20.4	18.5	18.5	10.3	25.0	21.8	21.1	21.4	22.3
10	Theo	-0.85	-1.66	-2.22	-2.20	-1.25	+0.22	+1.52	+2.27	+2.29	+1.48
	Meas.	-0.60	-1.22	-1.73	-1.82	-1.10	+0.07	+1.11	+1.71	+1.73	+1.11
	% Diff.	29.4	26.5	22.0	17.2	12.0	-	27.0	24.6	24.4	25.0
11	Theo.	+0.07	-0.17	-0.68	-1.24	-1.40	-0.76	+0.25	+1.04	+1.34	+0.96
	Meas.	+0.10	-0.08	-0.52	-1.05	-1.28	-0.74	-0.08	+0.72	+0.97	+0.70
	% Diff.	-	-	23.6	15.3	8.5	2.6	-	30.8	27.6	27.1
12	Theo.	+0.92	+1.30	+1.02	+0.26	-0.73	-1.39	-1.22	-0.67	-0.14	+0.10
	Meas.	+0.71	+1.01	+0.75	+0.15	-0.68	-1.25	-1.08	-0.59	-0.13	+0.06
	% Diff.	22.8	22.3	26.4	-	6.8	10.1	11.5	11.9	-	-
13	Theo.	+1.44	+2.26	+2.26	+1.55	+0.26	-1.20	-2.17	-2.22	-1.67	-0.86
	Meas.	+1.10	+1.75	+1.76	+1.21	+0.18	-1.02	-1.82	-1.83	-1.34	-0.68
	% Diff.	23.6	22.5	22.1	21.9	-	15.0	16.1	17.5	19.7	21.0
14	Theo.	+1.55	+2.50	+2.71	+2.18	+1.00	-0.61	-2.14	-2.95	-2.71	-1.60
	Meas.	+1.21	+2.01	+2.19	+1.82	+0.82	-0.50	-1.78	-2.52	-2.28	-1.32
	% Diff.	21.9	19.6	19.1	16.5	18.0	18.0	16.8	14.5	15.8	17.5
15	Theo.	+1.27	+2.11	+2.37	+2.08	+1.20	-0.10	-1.50	-2.57	-2.87	-1.90
	Meas.	+1.03	+1.76	+2.00	+1.77	+1.03	-0.09	-1.29	-2.23	-2.58	-1.64
	% Diff.	18.9	16.6	15.6	14.9	14.1	-	14.0	13.2	10.1	13.7
16	Theo.	+0.71	+1.19	+1.37	+1.25	+0.82	+0.11	-0.70	-1.40	-1.78	-1.42
	Meas.	+0.59	+1.03	+1.19	+1.11	+0.72	+0.10	-0.62	-1.28	-1.64	-1.32
	% Diff.	17.0	13.4	13.1	11.2	12.2	-	11.4	8.6	7.8	7.1

Theoreticals calculated by deflection theory - rib shortening not included.

Average % difference: 17.7

Table II

COLD SPRING CANYON ARCH
DEFLECTION STUDY

COMPARISON OF THEORETICAL AND MEASURED VERTICAL DEFLECTIONS (inches)

CABLE TIES ACTIVE

Load At		Panel Point 7	8	9	10	11	12	13	14	15	16
7	Theo.	-1.32	-1.64	-1.39	-0.64	+0.10	+0.76	+1.16	+1.26	+1.10	+0.66
	Meas.	-1.17	-1.50	-1.15	-0.58	0.00	+0.64	+0.96	+1.05	+0.89	+0.55
	%Diff.	11.4	8.5	17.3	9.4	-	15.8	17.2	16.7	19.1	16.7
8	Theo.	-1.72	-2.61	-2.36	-1.42	-0.14	+1;03	+1.84	+2.12	+1.90	+1.13
	Meas.	-1.41	-2.20	-1.95	-1.16	-0.16	+0.91	+1.53	+1.76	+1.56	+0.99
	% Diff.	18.0	15.7	17.4	18.3	-	11.7	16.8	17.0	17.9	12.4
9	Theo.	-1.42	-2.43	-2.70	-1.99	-0.61	+0.86	+1.98	+2.47	+2.32	+1.44
	Meas.	-1.10	-1.93	-2.21	-1.69	-0.59	+0.67	+1.53	+1.89	+1.78	+1.13
	% Diff.	22.6	20.6	18.2	15.0	3.3	22.1	22.7	23.5	23.2	21.5
10	Theo.	-0.76	-1.41	-2.06	-2.08	-1.22	+0.12	+1.40	+ 2.12	+2.15	+1.38
	Meas.	-0.48	-1.08	-1.56	-1.75	-1.08	+0.05	+1.00	+1.58	+1.58	+1.05
	% Diff.	37.0	23.4	24.3	15.9	11.5	-	28.6	25.4	26.5	23.9
11	Theo.	+0.09	-0.12	-0.63	-1.21	-1.39	-0.77	+0.20	+0.99	+1.30	+0.92
	Meas.	+0.12	-0.03	-0.53	-1.00	-1.27	-0.74	+0.04	+0.68	+0.92	+0.67
	% Diff.	-	-	15.9	17.3	8.7	3.9	-	31.3	29.2	27.2
12	Theo.	+0.90	+1.26	+0.98	+0.21	-0.74	-1.38	-1.20	-0.63	-0.08	+0.12
	Meas.	+0.64	+0.95	+0.75	+0.11	-0.71	-1.22	-1.03	-0.51	-0.08	+0.09
	% Diff.	28.9	24.6	23.5	-	4.0	11.6	14.1	19.0	-	-
13	Theo.	+1.33	+2.09	+2.08	+1.43	+0.21	-1.16	-2.07	-2.08	-1.52	-0.77
	Meas.	+1.01	+1.59	+1.64	+1.09	+0.15	-0.92	-1.71	-1.62	-1.10	-0.54
	% Diff.	24.1	23.9	21.1	23.8	-	20.7	17.4	21.2	27.6	29.9
14	Theo.	+1.39	+2.24	+2.45	+2.01	+0;95	-0.55	-1.98	-2.73	-2.50	-1.47
	Meas.	+1.10	+1.80	+1.98	+1.66	+0.77	-0.46	-1.62	-2.29	-2.05	-1.18
	% Diff.	20.9	19.6	19.2	17.4	19.0	16.3	13.1	16.1	18.0	19.7
15	Theo.	+1.12	+1.88	+2.14	+1.92	+1.15	-0.03	-1.34	-2.36	-2.67	-1.77
	Meas.	+0.92	+1.54	+1.80	+1.61	+0.97	-0.03	-1.13	-2.03	-2.34	-1.52
	% Diff.	17.8	18.1	15.9	16.1	15.6	-	15.6	14.0	12.3	14.1
16	Theo.	+0.63	+1.06	+1.24	+1.15	+0.80	+0.15	-0.61	-1.29	-1.67	-1.36
	Meas.	+0.54	+0.87	+1.09	+1.15	+0.64	+0.15	-0.53	-1.13	-1.48	-1.27
	% Diff.	14.2	17.9	10.5	0.0	20.0	-	13.1	12.4	11.4	6.6

Theoreticals calculated by deflection theory - rib shortening not included.

Average % difference: 18.1

Table III

COLD SPRING CANYON ARCH
DEFLECTION STUDY

CHANGE IN CABLE LOAD
DUE TO TEST LOAD
(Kips)

Test Load At Panel Point	Southwest Cable				Northwest Cable			
	Run Number				Run Number			
	3	4	5	Ave.	3	4	5	Ave.
7	+7.4	+7.6	+8.3	+7.8	-6.5	-6.4	-5.8	-6.2
8	+14.1	+14.5	+15.1	+14.6	-9.3	-8.7	-7.8	-8.6
9	+14.3	+14.7	+15.5	+14.8	-9.2	-8.8	-7.9	-8.6
10	+8.9	+9.6	+10.1	+9.5	-7.8	-7.5	-6.9	-7.4
11	+2.8	+2.7	+2.9	+2.8	-4.3	-4.0	-3.6	-4.0
12	-1.6	-1.7	-1.7	-1.7	+3.1	+3.0	+2.9	+3.0
13	-3.0	-3.2	-3.4	-3.2	+11.9	+11.4	+11.3	+11.5
14	-	-3.4	-3.8	-3.6	-	+17.6	+17.6	+17.6
15	-3.1	-3.5	-3.8	-3.5	-17.7	+16.9	+17.4	+17.3
16	-2.8	-3.2	-3.2	-3.1	+10.6	+9.4	+10.4	+10.1

Cable load without test load application:

Southwest - beginning run 3: 3.0, end run 5: 3.9 kips.
Northwest - beginning run 3: 11.9, end run 5: 8.7 kips.

Table IV

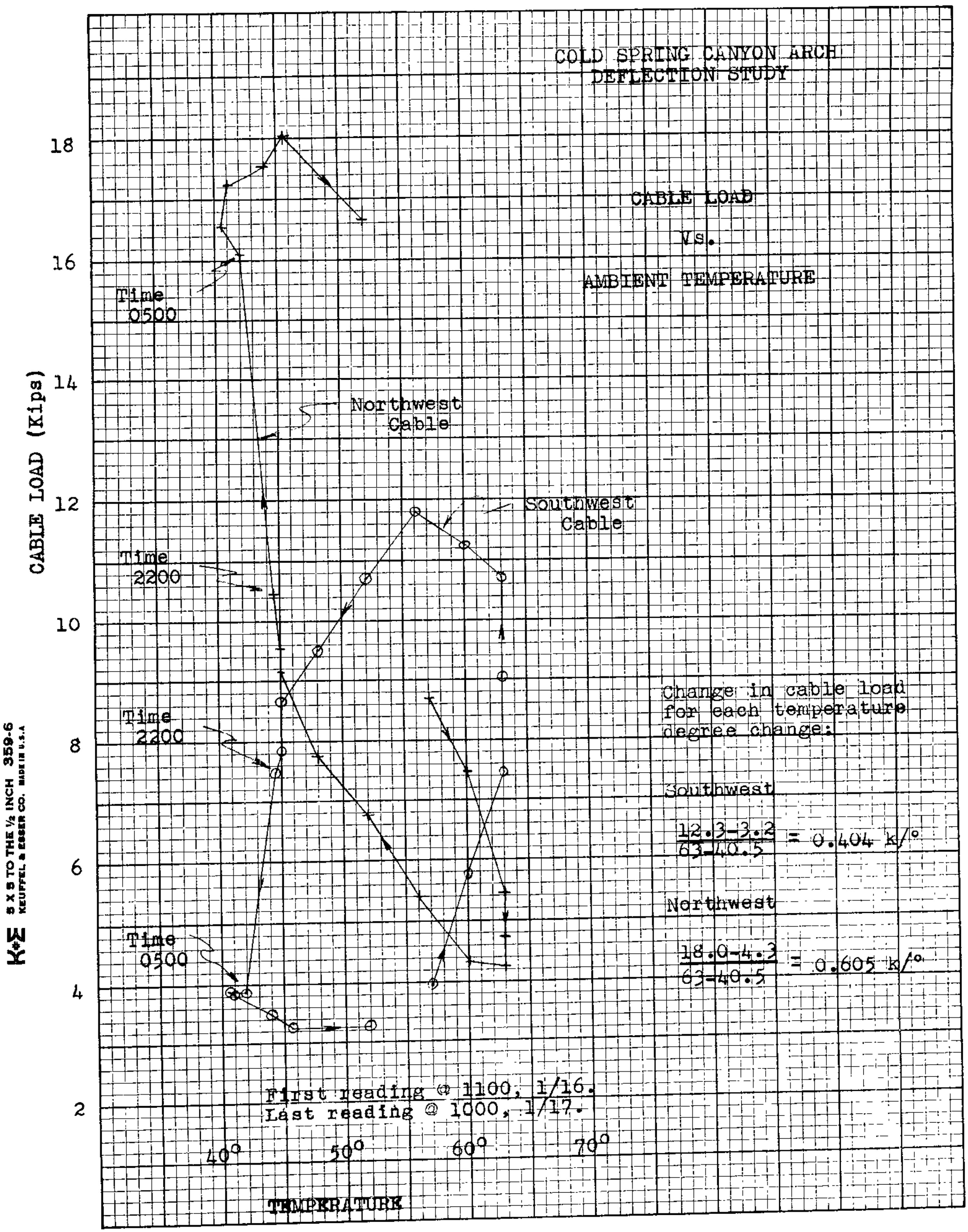

COLD SPRING CANYON ARCH
DEFLECTION STUDY
CABLE LOAD
Vs.
AMBIENT TEMPERATURE
CABLE LOAD (Kips)
18
16
14
12
10
8
6
4
2
Time 0500
Northwest Cable
Southwest Cable
Time 2200
Time 2200
Time 0500
Change in cable load for each temperature degree change:
Southwest
12.3-3.2 / 63-40.5 = 0.404 k/°
Northwest
18.0-4.3 / 63-40.5 = 0.605 k/°
First reading @ 1100, 1/16.
Last reading @ 1000, 1/17.
40°
50°
60°
70°
TEMPERATURE
K+E 5 X 5 TO THE ½ INCH 359-6
KEUFFEL & ESSER CO. MADE IN U.S.A.

Figure 3